



# **BIONICO**

## **BIOGAS MEMBRANE REFORMER FOR DECENTRALIZED H<sub>2</sub> PRODUCTION**

Call: H2020-JTI-FCH-2014-1 Topic: FCH-02.2-2014 Decentralized hydrogen production from clean CO<sub>2</sub>-containing biogas

# SUMMARY

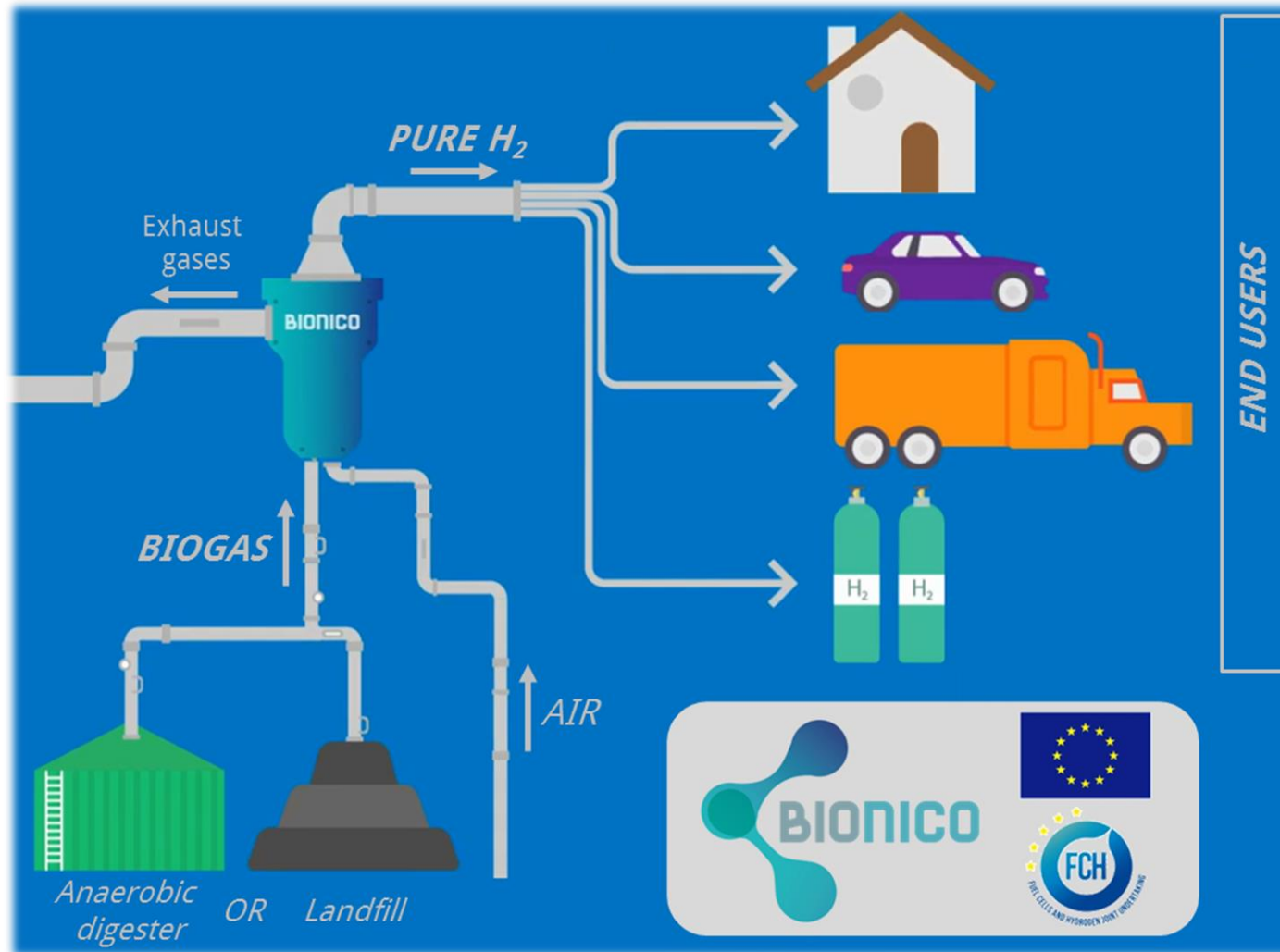
BIONICO **aims** at developing a **novel reactor** configuration at a **larger scale** to produce **H<sub>2</sub>** from **biogas** production power plant based on:

- Design, develop and test a **new concept** reactor integrating hydrogen **production** and **purification** on a **single unit**
- Design, develop and testing of a **catalytic membrane reactor** for the production of highly-purity hydrogen from biogas, scaling up new H<sub>2</sub> selective **membranes** and **catalyst** production
- Develop a **flexible system** (including the advance control and BoP components) capable of producing pure hydrogen from **biogas of different compositions** in a unique reactor system.

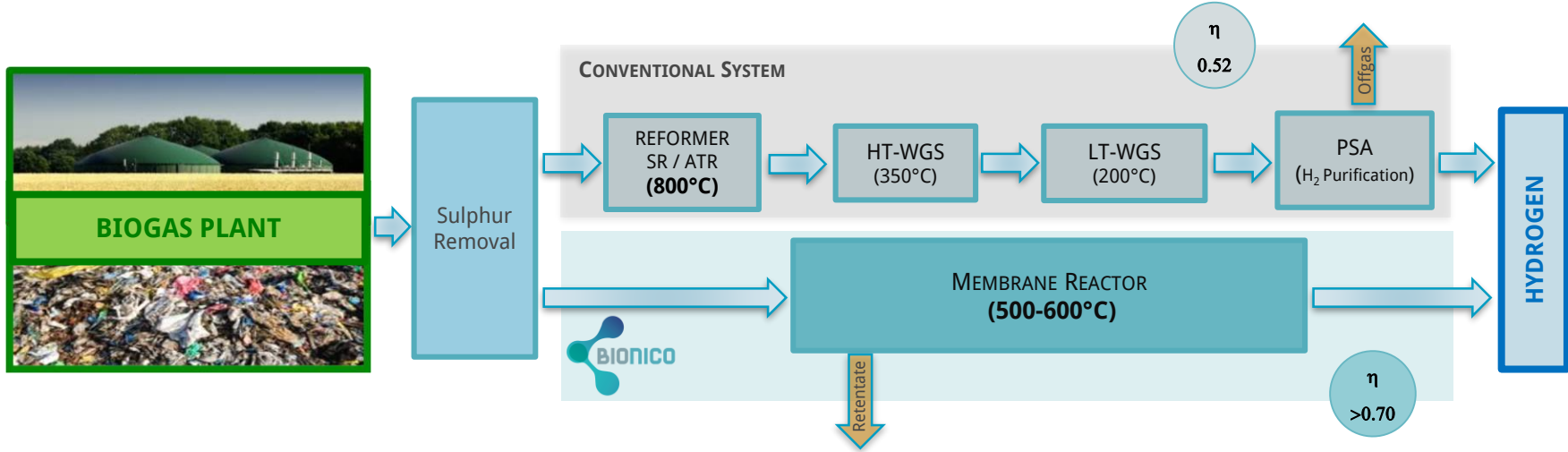
The main idea of BIONICO is to design and demonstrate an **efficient biogas-to-hydrogen conversion system** at real plant conditions using process intensification.



# CONCEPT



# WHY BIONICO?



## Reference Case Results

	units	SR	ATR
Biogas feed	Nm <sup>3</sup> /h	39.5	63.5
Total Biogas Input	kW	229	368
System efficiency	% <sub>LHV</sub>	51.7	27.8
Hydrogen delivery pressure	bar	20	20
Hydrogen production cost	€/kg	4.21	6.37

Two reference cases (based on SR and ATR) are identified to benchmark the performance of the BIONICO concept

The target of BIONICO is a system efficiency above 70%<sub>LHV</sub>, which is about 25% higher than SR (52%<sub>LHV</sub>). The higher efficiency together with equipment savings will end up in lower hydrogen production costs.

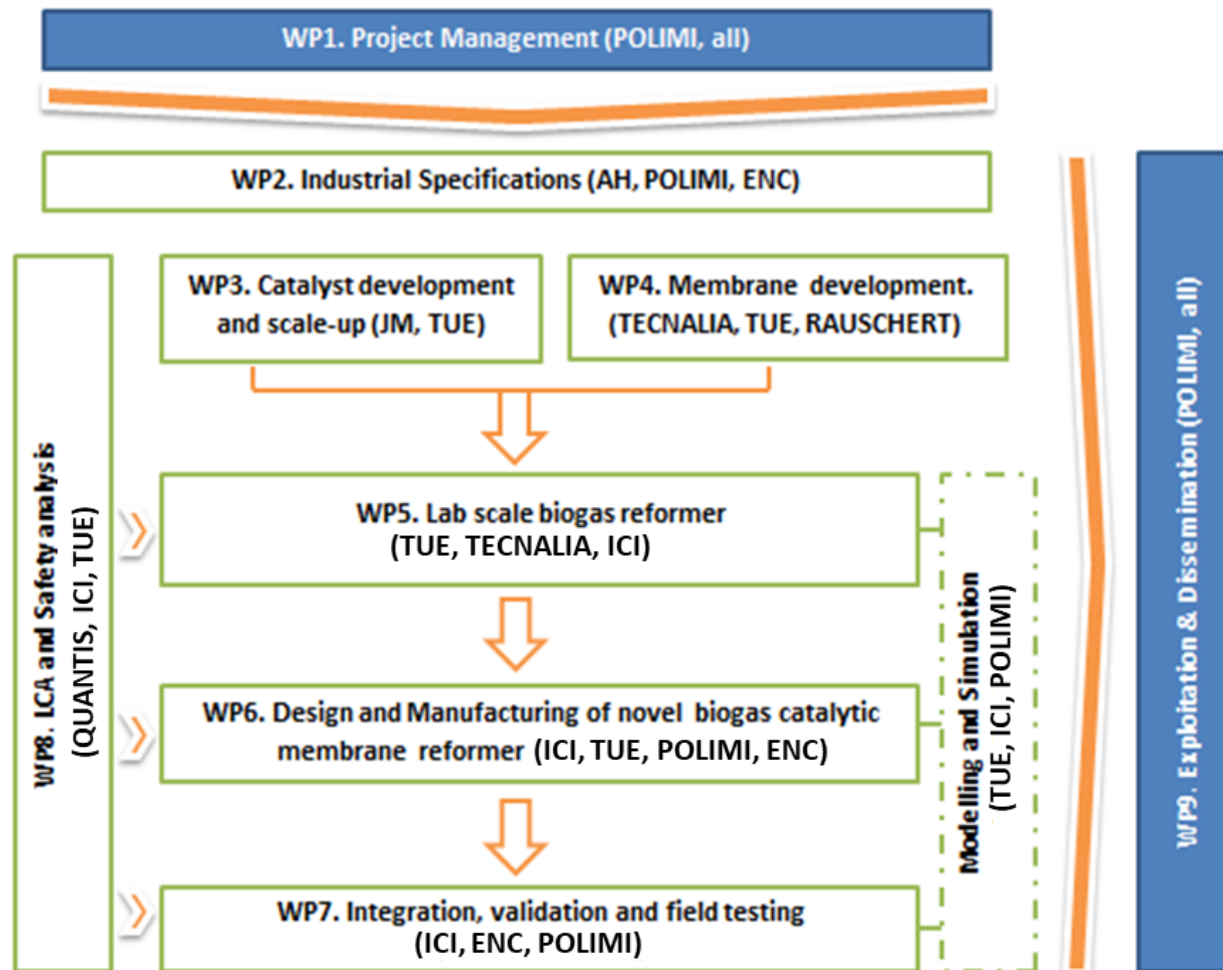
# PARTNERSHIP

Multidisciplinary and complementary team: 8 top level European organisations from 7 countries including 3 Research Institutes and Universities and 4 representative top industries in different sectors (from catalyst to membranes to chemical and process engineering, etc.)

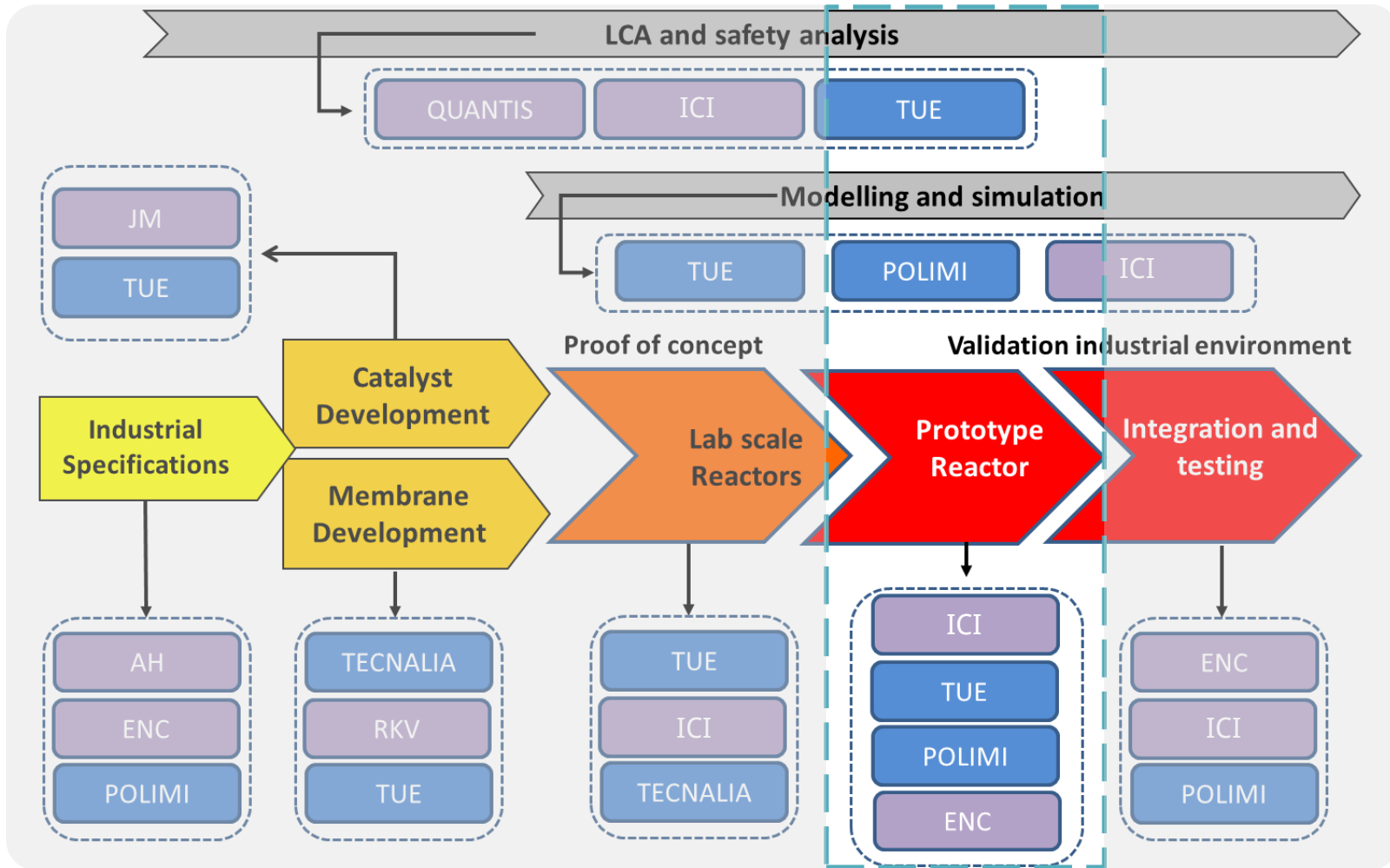
- POLIMI, Italy
- TU/e, The Netherlands
- Abengoa, Spain
- Tecnalia, Spain
- ICI caldaie, Italy
- Johnson Matthey, UK
- ENC Energy, Portugal
- Rauschert, Germany
- Quantis, Switzerland



# WORK STRUCTURE



# PARTNERSHIP SYNERGIES



# NOVEL CATALYST

## GOAL

Development of highly active reforming catalysts to produce hydrogen from diverse biogas mixture coupled with steam and air in a fluidised bed regime.

## THREE YEARS PROJECT ACTIVITIES

- PGM doped alumina catalysts have been tested under biogas reforming conditions for dry, steam or autothermal reforming
- Coke formation resistance improvement

## ACHIEVEMENTS

- 1<sup>st</sup> generation catalyst and 2<sup>nd</sup> generation catalyst able to work under fluidisation regime and at low temperature
- Final Catalyst formula produced and shipped to ICI



# NOVEL MEMBRANE & SUPPORT

## GOAL

Development of Pd based tubular supported membranes, for application in biogas reforming catalytic membrane reactors

## THREE YEARS PROJECT ACTIVITIES

- Preparation of porous ceramic tubes of different diameters and materials for their use as supports for thin Pd-based membranes
- Manufacturing of thin film (<5  $\mu\text{m}$  thick) Pd-Ag and Pd-Ag-Au membranes on top of the ceramic supports.
- Development of new finger-like porous asymmetric ceramic supports in which one of the ends of the tube is a closed porous part.



*Finger-like asymmetric porous ceramic supports*

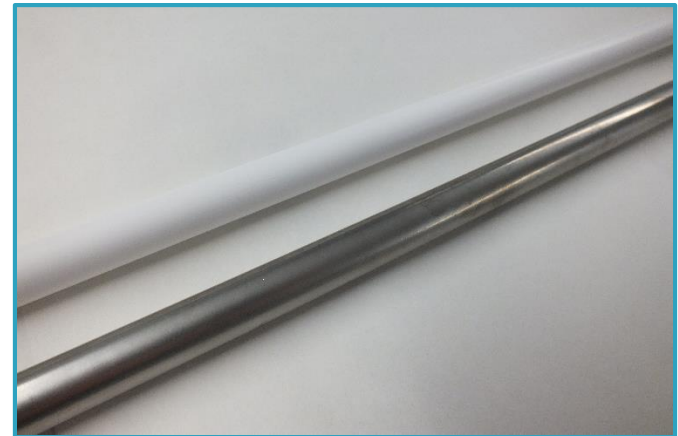
# NOVEL MEMBRANE & SUPPORT

## GOAL

Development of Pd based tubular supported membranes, for application in biogas reforming catalytic membrane reactors

## ACHIEVEMENTS

- 1<sup>st</sup> generation membrane & support
- Installation of a new plating system for preparation of >40 cm long membranes.
- 2<sup>nd</sup> generation membrane & support.
  - Thin Pd-Ag layers have been deposited onto the 50 cm long finger-like supports.
- Definition of criteria for support quality
- Improvement of manufacturing procedure for membrane prototype production
- Membranes for prototype preparation



*2<sup>nd</sup> generation thin film Pd-alloy supported membranes (>40 cm long)*



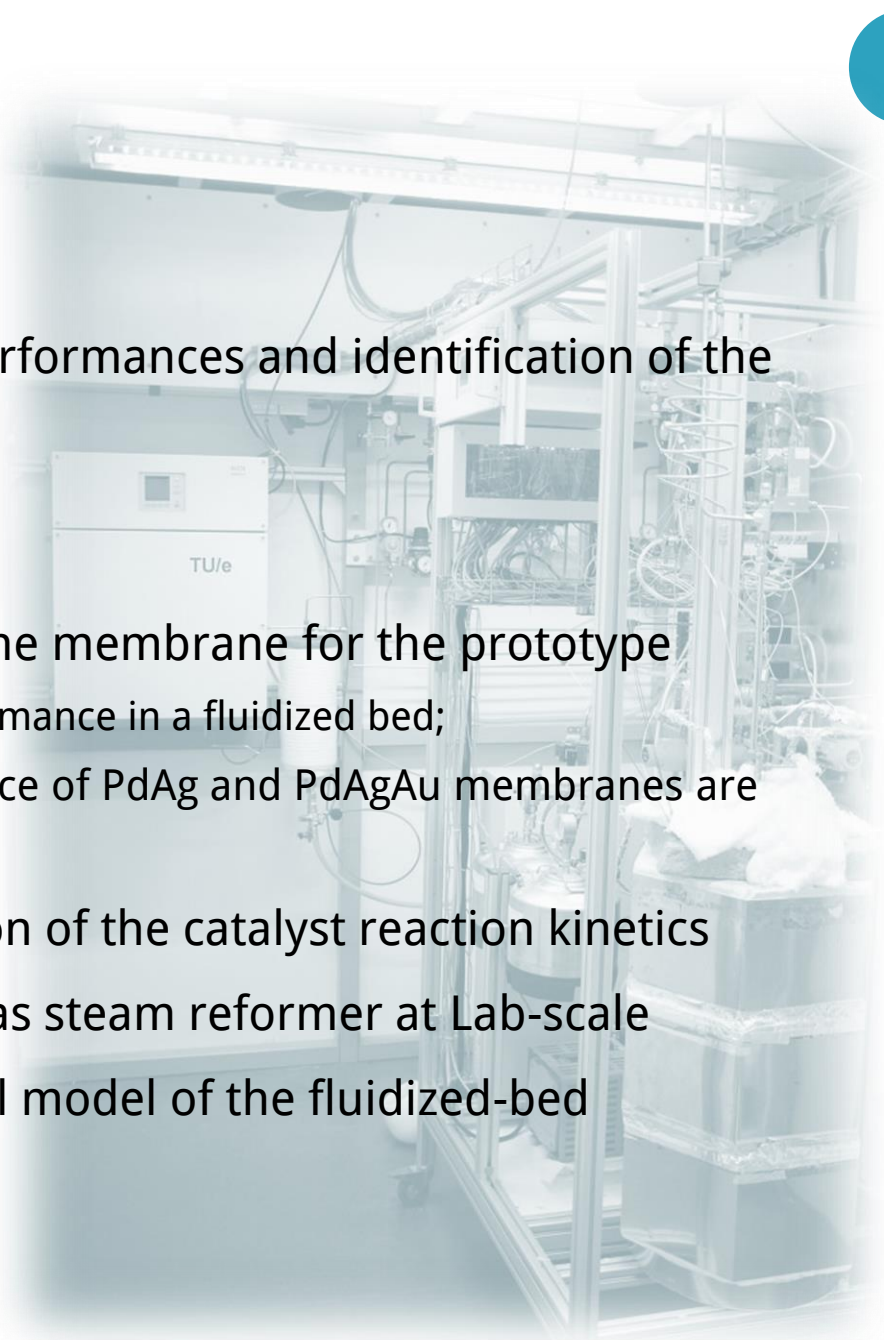
# LAB SCALE REACTOR

## GOAL

Definition of the lab scale reactors performances and identification of the best design for prototype pilot.

## THREE YEARS ACTIVITIES

- Selection and characterization of the membrane for the prototype
  - Study of long-term membrane performance in a fluidized bed;
  - The effect of  $H_2S$  on the performance of PdAg and PdAgAu membranes are studied
- Obtain a comprehensive description of the catalyst reaction kinetics
- Design and demonstration of biogas steam reformer at Lab-scale
- Development of phenomenological model of the fluidized-bed membrane reactor



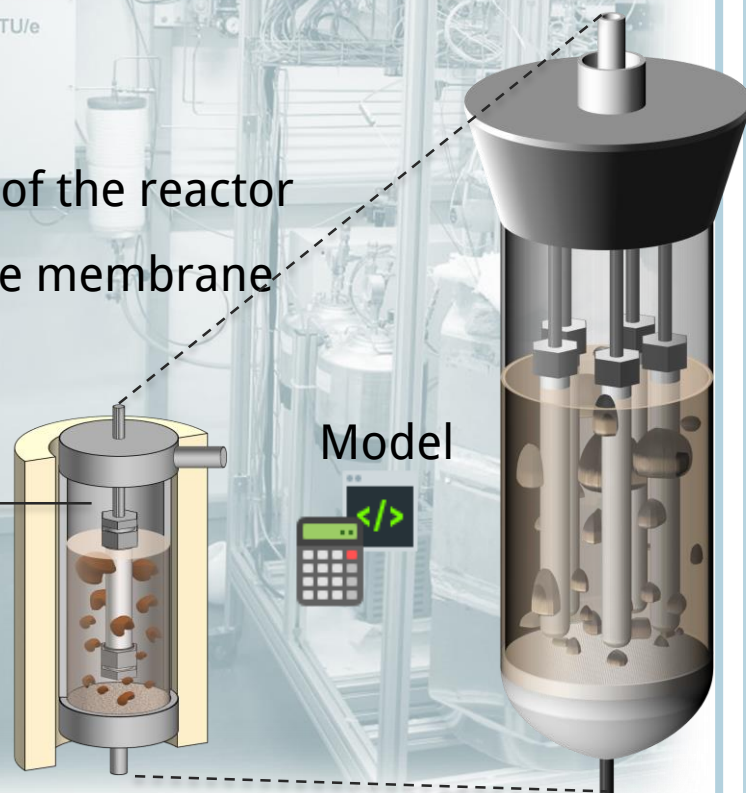
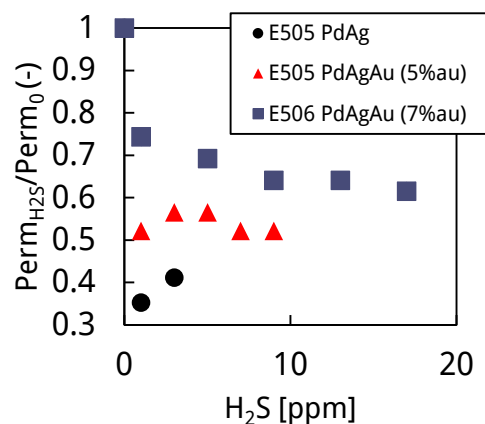
# LAB SCALE REACTOR

## GOAL

Definition of the lab scale reactors performances and identification of the best design for prototype pilot.

## ACHIEVEMENTS

- Integration of catalyst and membrane
- One dimensional phenomenological model of the reactor
- Effect of Au addition on H<sub>2</sub>S resistance of the membrane

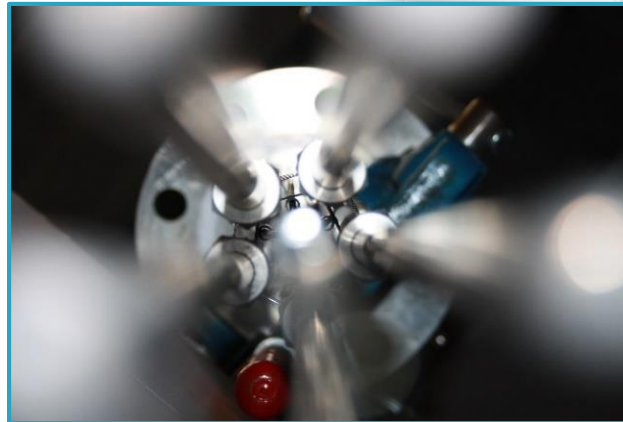


# LAB SCALE REACTOR

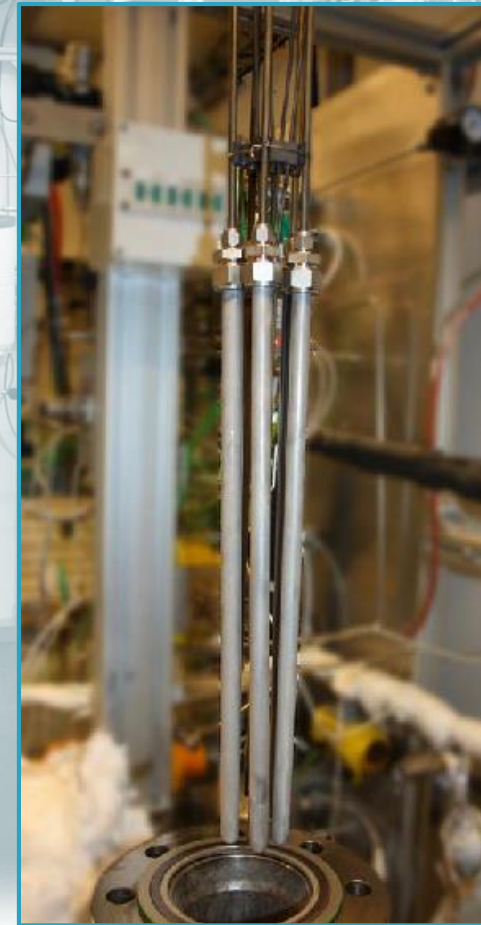
## GOAL

Definition of the lab scale reactors performances and identification of the best design for prototype pilot.

## ACHIEVEMENTS



- Successful description of concentration polarization in the reactor model
- Lab scale system with 5 membranes equal to the once that will be used in the pilot, as well as the catalyst, have been tested



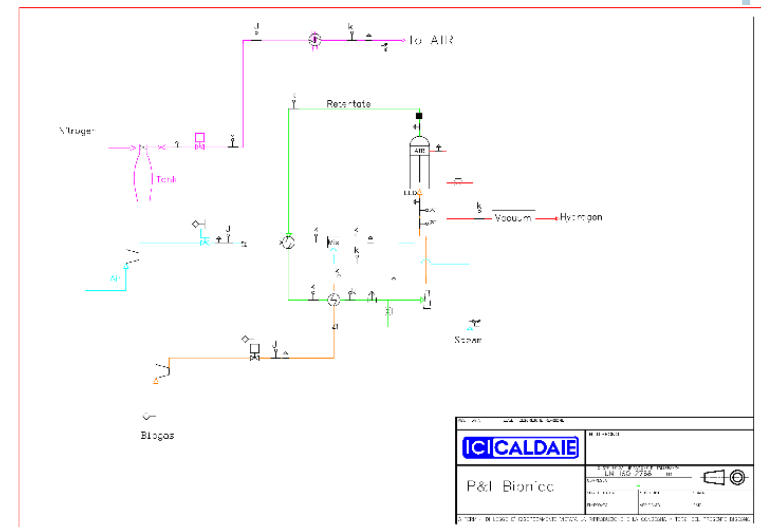
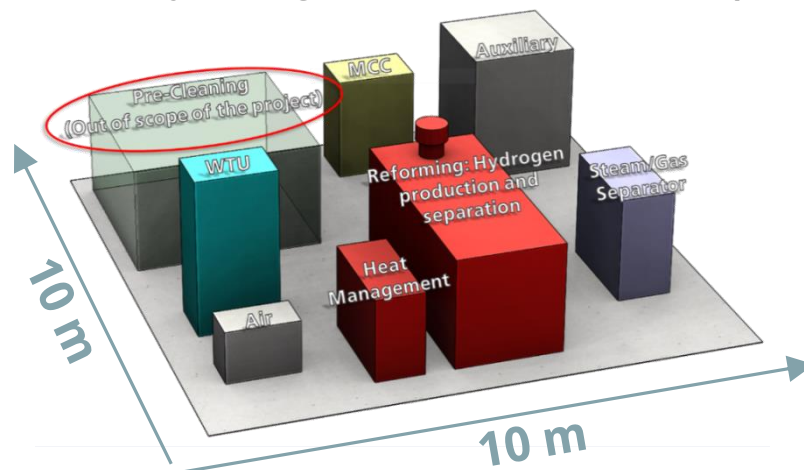
# PROTOTYPE REACTOR

## GOAL

Final design and construction of MR prototype for the production of approximately 100 kg/day of pure hydrogen

## THREE YEARS PROJECT ACTIVITIES

- Preliminary design of the prototype catalytic membrane reactor at large scale including control system design
- Preliminary design of the balance of plant



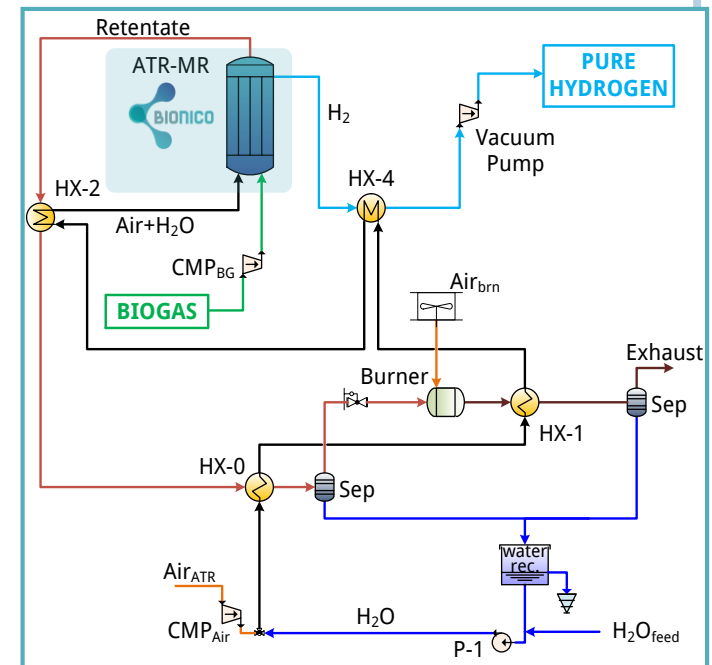
# PROTOTYPE REACTOR

## GOAL

Final design and construction of MR prototype for the production of approximately 100 kg/day of pure hydrogen

## ACHIEVEMENTS

- A techno-economic optimization of BIONICO system was assessed
- Different operating conditions ( $T$ ,  $p$ ,  $S/C$ ), biogas compositions and permeate side configuration were investigated
- Membrane reformer designed and manufactured by ICI



# INTEGRATION & TESTING AT BIOGAS PRODUCTION SITE

## GOAL

Final evaluation of the innovative process to directly produce pure hydrogen in a real biogas production site (ENC Landfill plant)

## THREE YEARS PROJECT ACTIVITIES

- Definitions of input needed for starting the plant licensing procedure
- Evaluating the integration of the prototype reactor in the overall BIONICO system at biogas production site



*Biogas cleaning unit*



*Landfill plant*



# LIFE CYCLE ASSESSMENT & SAFETY ISSUES

## GOAL

Development strategy towards sustainable solutions and provide guidance on how to operate the reactor prototype under safe conditions.

## THREE YEARS PROJECT ACTIVITIES

- Refined goal & scope of LCA analysis, in particular, with further clarifications with regard to: (i) reference systems (baseline), i.e., SMR and ATR, (ii) level of details of inventory modeling and (iii) system boundaries
- Improved data collection for key data points, especially related to functional unit, biogas input, conversion efficiency, energy and water use as well as direct GHG emissions during conversion processes
- Final LCA analysis between BIONICO CMR and reference technologies
- In progress of developing applicable safety protocol

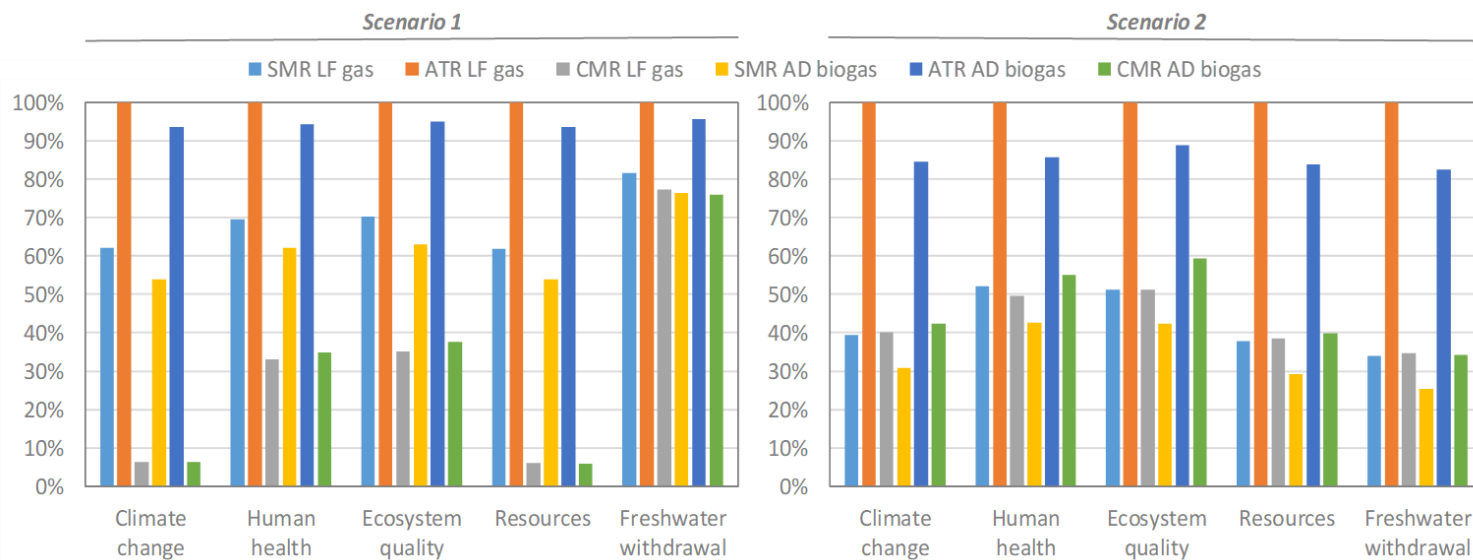
# LIFE CYCLE ASSESSMENT & SAFETY ISSUES

## GOAL

Development strategy towards sustainable solutions

## ACHIEVEMENTS

- Refined LCA modeling and results: BIONICO CMR only performs significantly better for most environmental indicators than reference systems when biogas utilization is limited (Scenario 1, Left)



# LIFE CYCLE ASSESSMENT & SAFETY ISSUES

## GOAL

Provide guidance on how to operate the reactor prototype under safe conditions.

## ACHIEVEMENTS

- ICI has performed safety assessment during the reactor design based on the following safety standards and directives: Machinery Directive (2006/42/EC), Pressure Equipment Directive (2014/68/EU), EN 60079-10-1 Explosive atmospheres Part 10-1: Classification of areas - Explosive gas atmospheres (2015)
- Inconel has been chosen as construction material for reactors following the safety analysis
- ICI is working on more specific and complete analysis with updated P&ID and the BoP information

# DISSEMINATION ACTIVITY

BIONICO partners travelled for thousands of kilometers to disseminate the project and its achievements in the first three years of the project

- Papers (6)
  - Potentiality of a biogas membrane reformer for decentralized hydrogen production, *Chem. Eng. and Processing: Process Intensification, Open Access*
  - On concentration polarisation in a fluidized bed membrane reactor for biogas steam reforming: Modelling and experimental validation, *Chemical Engineering Journal, Open Access*
  - Palladium based membranes and membrane reactors for hydrogen production and purification: An overview of research activities at Tecalia and TU/e, *Int. Journal of Hydrogen Energy*
  - Green hydrogen production from raw biogas: a techno-economic investigation of conventional processes using pressure swing adsorption unit, *Processes, Open Access*
  - Achievements of EU projects on membrane reactor for hydrogen production, *Journal of Cleaner Production, open access*
  - Effect of Au addition on hydrogen permeation and the resistance to H<sub>2</sub>S on Pd-Ag alloy membranes, *Journal of Membrane Science*



# DISSEMINATION ACTIVITY

BIONICO partners travelled for thousands of kilometers to disseminate the project and its achievements in the first three years of the project

- Presentations (12+) & Posters (7)

- 2018 - Life cycle assessment and economic analysis of an innovative biogas membrane reformer for hydrogen production, *ICH2P 2018, Croatia*
- 2018 - 15 Times More Memb. Area: How scaling-up affects biogas steam reforming in a fluidized-bed membrane reactor, *ICIM 2018, Germany*
- 2018 - On the mass transfer rates in fluidized bed membrane reactors, *ICIM 2018, Germany*
- 2018 - On the mass transfer rates in fluidized bed, *ISCRE 25, Italy*
- 2018 - Palladium membrane reactors for hydrogen production, *EHEC 2018, Spain*
- 2018 - Design and Demonstration of a lab-scale fluidized-bed membrane reactor for biogas steam reforming, *EHEC 2018, Spain*
- 2017 - Stability of Ceramic supported PdAg membranes for hydrogen production in a fluidized bed membrane reactor, *ICCMR, USA*
- 2017 - MRPI workshop: BIONICO activities mentioned together with other projects, *MR4PI, Italy*
- 2016 - Achievements of EU projects on membrane reactor for hydrogen production, *SDEWES conference, Portugal*
- 2016 - Palladium based membranes and membrane reactors for hydrogen production and purification, *WHEC 2016, Spain*
- 2016 - Fluidized bed membrane reactors for hydrogen production using thin Pd-based (<5 µm) supported membranes, *ICIM conference, USA*
- 2016 - Effect of the addition of Au in Pd-Ag alloy membranes on the hydrogen permeation performance under the presence of H<sub>2</sub>S, *ICIM conference, USA*
- 2017 - Bionico project - preliminary assessment of hydrogen production from biogas using a fluidised bed catalytic membrane reactor, *Regatec, Pacengo, Italy*
- 2017 - Potentiality of a biogas membrane reformer for decentralized hydrogen production, *MR4PI workshop, Verona Italy*
- 2016 - Biogas membrane reformer for decentralized H<sub>2</sub> production, *EBA conference, Belgium*
- 2016 - Biogas membrane reformer for decentralized H<sub>2</sub> production, *WHEC, Spain*
- 2016 - Steam reforming of biogas in a fluidized bed membrane reactor for pure hydrogen production, *Dutch Membrane Society, The Netherlands*
- 2016 - Preparation and characterization of thin Pd-ag-au supported membranes for hydrogen separation, *Poster at EMS Summer School, Italy*

- New Press Release in CIB magazine: [LINK](#)



# BIONICO PROJECT MEETING – M32

BIONICO M32 meeting was held in ICI caldaie (Verona, Italy). It was an opportunity to discuss on the project status and plan next project activities and to visit ICI caldaie facilities.



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# Thank you for your attention!



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